



LONG-LIFE SUPER-TF SPHERICAL ROLLER BEARINGS

FOR WIND TURBINE MAIN SHAFTS



STAY IN MOTION. STAY IN CONTROL.



SUSTAINABLE SOLUTIONS

ROLLING BEARINGS FOR WIND ENERGY

Modern turbines are immense structures, typically weighing over 200 tons with each rotor blade spanning 120 feet or more. Operating in high and frequently changing winds, the mass of these systems, the staggering kinetic forces, and the uniquely challenging operating conditions place significant demands on a wind turbine's components - particularly the bearings.

Reliability is essential. With remote and restricted access onshore and offshore, service and maintenance on these machines are complex and costly and scheduled sparingly - with intervals as long as ten years. Any incident of unplanned downtime for bearing repairs or replacement has intolerable consequences to cost-competitive energy generation.

For turbine builders and operators alike, predictable and cost-effective operation requires a development partner to simulate, test, and deploy advanced product technologies that deliver the highest level of performance and efficiencies.

A partner like NSK.

LONG-LIFE RELIABILITY: SUPER-TF BEARINGS

Wind turbine main shaft bearings work under immense and continuous dynamic wind loads while rotating at ultra-low speeds, a fraction of those at which they typically operate. The interaction of these conditions and the resulting mechanical stress on power train components presents challenges to bearings for wind turbine main shafts that can result in excessive wear and unattainable requisite life requirements.

That is, for conventional bearing solutions.

NSK's Super-TF (STF) spherical roller bearings for main shafts are anything but conventional. Engineered to deliver superior and sustainable performance – through advanced material technology and applied manufacturing process controls – STF bearings are built to endure, delivering high-capacity performance for a significantly longer and more reliable operating life.

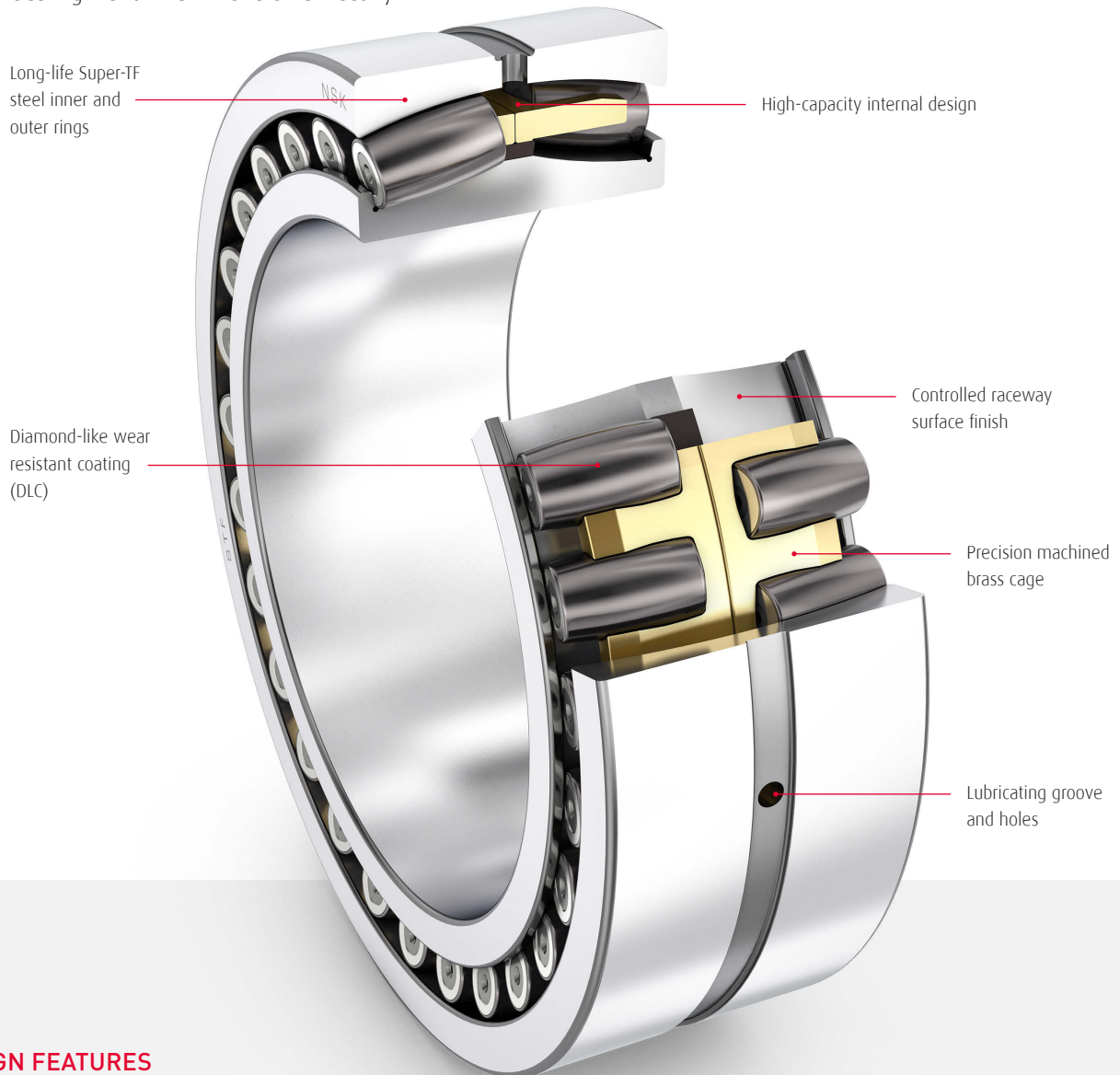
PROVEN ADVANTAGES:

- › Super-TF steel promotes longer life with dramatically increased resistance to wear and seizure
- › Special roller surface treatment - DLC coating - increases roller toughness and endurance
- › Controlled raceway surface finish improves lubrication performance and augments wear resistance



DESIGN AND OPERATING ADVANTAGES

Super-TF (STF) series bearings are designed to deliver outstanding durability in operating environments subject to contamination, or conditions that instigate severe wear. Utilizing advanced material engineering and heat treatment technology, they provide the longest bearing life for the wind turbine industry.



DESIGN FEATURES

- › Ultra-large spherical roller bearing with optimized, high-capacity internal design
- › Bearing rings manufactured with long-life Super-TF steel for dramatically longer service life
- › Rollers are treated with wear-resistant diamond-like coating (DLC)
- › Heavy duty, precision machined two-piece brass cage
- › Special / custom radial internal clearance
- › Outer ring lubricating groove with optimized size and quantity of lubricating holes
- › Superior raceway surface finish process for main shaft applications

1 ADVANCED MATERIAL TECHNOLOGY

- › Super-TF steel promotes longer life with dramatically increased resistance to wear and seizure

2 MACHINED BRASS CAGE

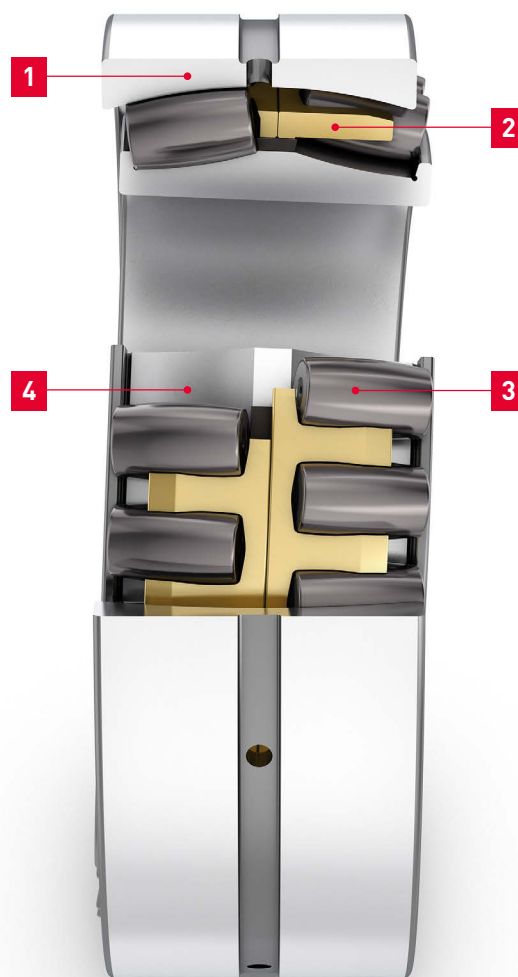
- › Heavy-duty two-piece cage design delivers superior performance in applications subject to heavy and/or impact loading
- › Cage pocket geometry and finger length provide superior roller guidance and controlled roller skew
- › Precision-machined contours optimize lubricant flow to rolling contact surfaces

3 WEAR-RESISTANT ROLLERS

- › Diamond-like coating (DLC) increases roller surface toughness with extremely low friction and considerable hardness
- › Mitigates roller wear and damage, contributing to a significant increase in bearing service life

4 ADVANCED RACEWAY SURFACE FINISH

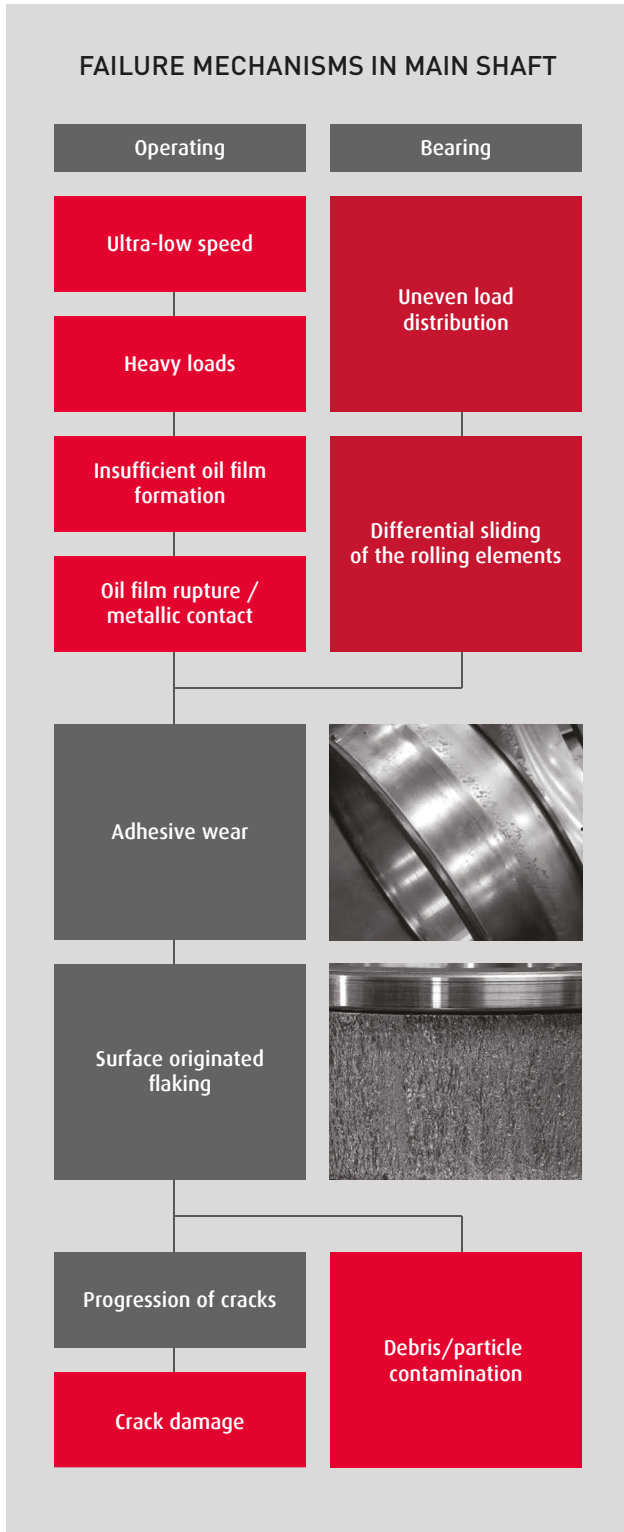
- › Superior ring grinding technology, in conjunction with optimized roller-to-raceway profiles, controls roller motion within the bearing, reducing bearing wear and improving bearing fatigue life
- › Controlled asperity peaks - at a micro level - improve lubrication performance and augment wear resistance



LONG-LIFE SUPER-TF STEEL

- › NSK's advanced material composition and proprietary heat-treatment technology
- › Organically higher dynamic load capacity – up to 23%
- › Exponentially longer life in contaminated and boundary lubrication conditions versus ordinary carburized steel
- › As low as one-third the normal rate of wear versus standard bearing steel
- › Up to 40% improvement to seizure resistance versus standard bearing steel

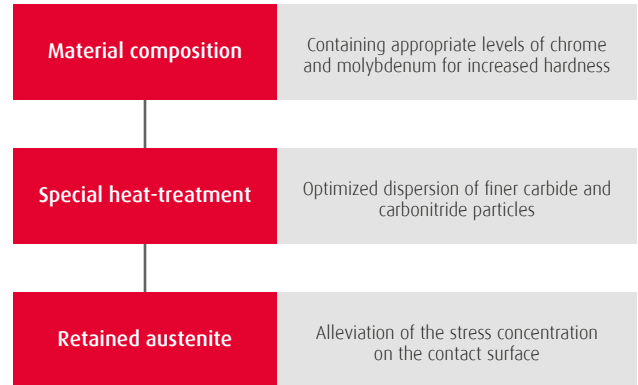
HIGH PERFORMANCE FACTORS: SUPER-TF STEEL



SUPER-TF (STF) MATERIAL TECHNOLOGY

With the expectation to operate successfully for 20 years or longer, durability is crucial for the spherical roller bearings used in wind turbine main shafts. During their operating life they must endure immense radial and axial loads while operating at ultra-low speeds. Effective lubrication of rolling contact surfaces is compromised, and rollers are prone to differential slip - initiating inordinate stress, wear and potential bearing failure.

NSK's Super-TF (STF) series spherical roller bearings are designed to deliver outstanding durability in these environments. Through advanced material engineering and heat treatment technology, they mitigate the impact of these conditions and perform with superior resistance to wear, seizure and heat.



In severe, contaminated, and boundary-lubrication conditions, Super-TF bearings deliver exponentially longer life when compared to conventional carburized bearings. For main shaft applications this translates to achieving total cost and performance expectations without unexpected downtime and maintenance incidents.

Life test: Result under foreign contamination

| | |
|-----|--------------------------|
| 1 | Catalogue life |
| 0.2 | General carburized steel |
| 2 | Super-TF steel |

* tapered roller bearings

Life test: Result under boundary lubrication ($\Lambda=0.3$)

| | |
|-----|--------------------------|
| 1 | General carburized steel |
| 5.5 | Super-TF steel |

* ball-rod rolling contact fatigue test

DEVELOPMENT OF SUPER-TF STEEL

SUPER-TF LONG-LIFE STEEL

Bearings can be required to operate under conditions where lubricating oil is easily contaminated. Metal particles or casting sand in the lubricant create dents in the rolling contact surfaces, and stress concentrated around these dents eventually leads to cracking and to surface-originating flaking. Reducing the concentration of stress around the shoulders of surface dents is directly related to achieving longer service life from the bearing.

NSK research has revealed that a high level of retained austenite is an extremely effective means of maximizing the r/c value around surface dents in the bearing material and reducing stress concentration. However, austenite itself has a soft microstructure and reduces the hardness of bearing material. To meet the seemingly conflicting needs for greater hardness with a higher level of retained austenite, NSK has adopted an advanced material composition and proprietary heat-treatment technology to promote the uniform distribution of larger numbers of finer carbide and carbonitride particles in the bearing material. Super-TF bearing steel (SAC2) contains specific amounts of chrome and molybdenum to optimize the formation of carbides.

Figures 2 and 3 illustrate that Super-TF Bearings have a greater amount of fine-size carbide and carbonitride particles than ordinary carburized bearings, giving them a greater degree of hardness as well as higher retained austenite for a long service life (Fig. 4).

Fig. 1 - Relationship of r/c value to retained austenite

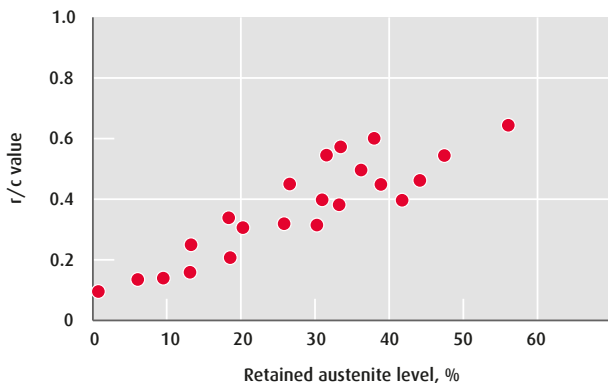


Fig. 2 - Average diameter of carbide and carbonitride particles, Super-TF bearing

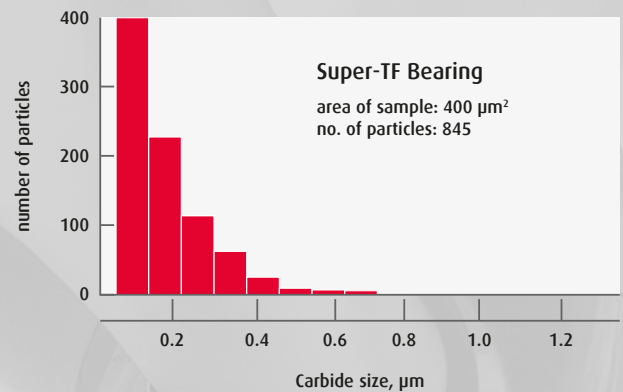


Fig. 3 - Average diameter of carbide and carbonitride particles, ordinary carburized bearing

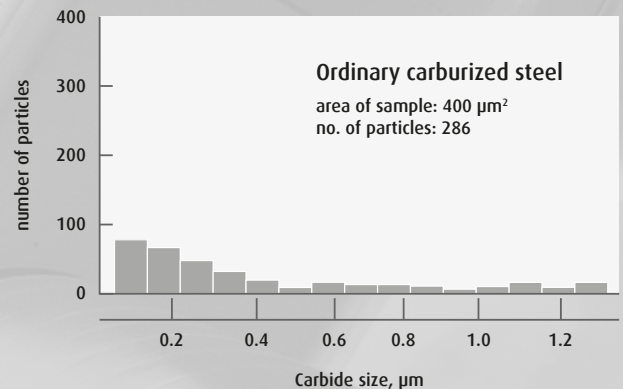
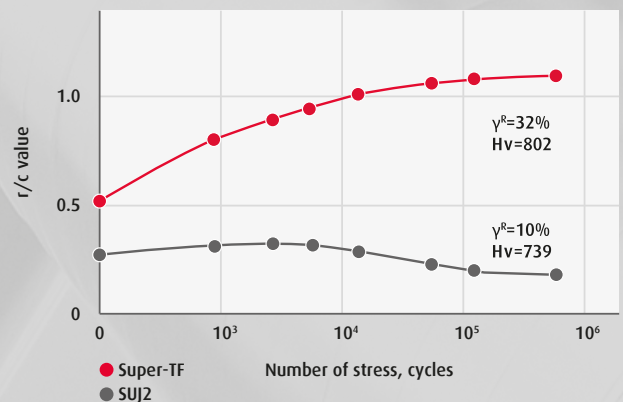


Fig. 4 - Change of r/c value under repeated stress

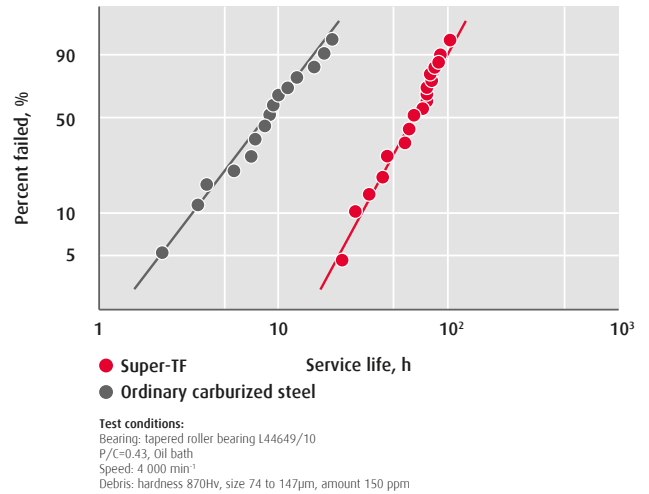


Service Life Under Contaminated Lubrication Conditions

Bearing service life is generally impacted by the conditions in which the bearing is used and by the amount of contamination in the lubricant. Under contaminated lubricated conditions, service life may fall to as little as 1/5 of the catalog life.

Designed specifically to deliver longer service life in such conditions, Super-TF Bearings can achieve service life that exceeds the catalog life of comparable conventional products. In service life tests conducted under contaminated lubrication conditions, the L_{10} life of Super-TF Bearings is more than ten times that of ordinary carburized steel bearings.

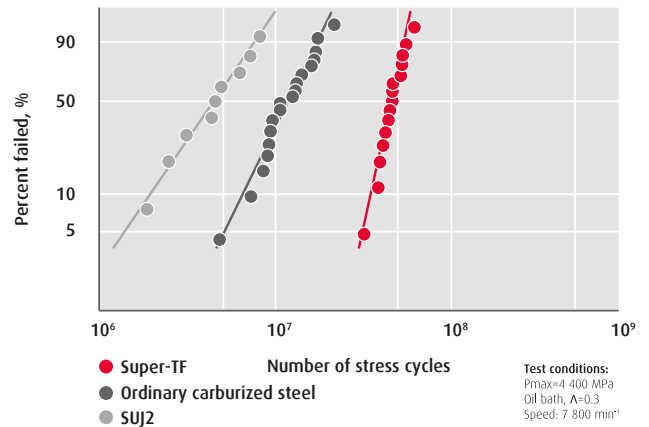
Fig. 5 - Service life under contaminated lubrication



Service Life Under Boundary Lubrication Conditions

Where there is an insufficient amount of EHL film, bearing damage from metal-to-metal contact occurs. In service life tests conducted under conditions where the oil film parameter is very small, peeling damage occurs. With Super-TF Bearings, the reduced concentration of stress around the projections of the contact area delivers a service life approximately 5.5 times greater than that of ordinary carburized steel bearings.

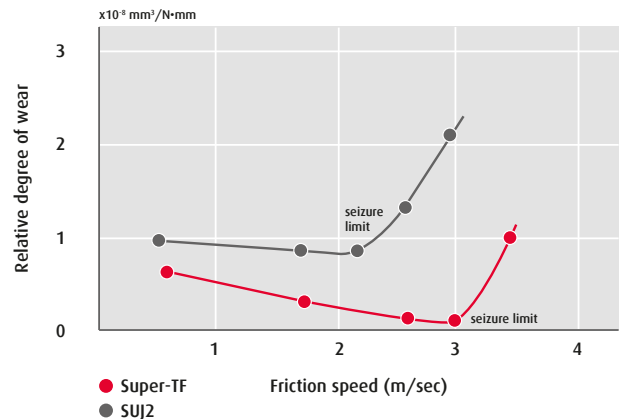
Fig. 6 - Service life tests under boundary lubrication



Wear and Seizure Resistance

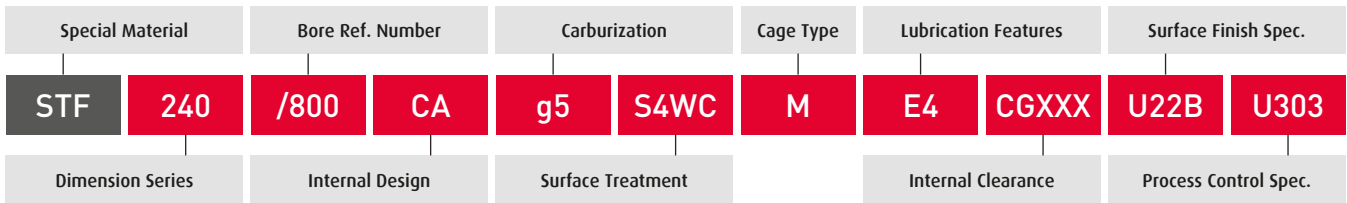
The dispersion of a large number of fine carbides and nitrides in the bearing material increases STF bearings' resistance to wear and seizure. In a Sawin test showing the degree of wear and the seizure limit, Super-TF Bearings demonstrate superior wear resistance to SUJ2 steel with 40% greater seizure resistance.

Fig. 7 - Comparison of wear resistance



DESIGNATION SYSTEM

SUPER-TF SPHERICAL ROLLER BEARINGS FOR MAIN SHAFT



| DESIGNATION | ATTRIBUTE | |
|------------------------------|-----------|--|
| Special Material Designation | blank | standard bearing steel |
| | STF | long-life Super-TF™ steel |
| Dimensional Series | 240 | wide series 240 most commonly used in main shaft applications |
| | 230 | |
| Bore Reference Number | | 500 mm and greater expressed with a “/” eg. /500 = 500 mm |
| Internal Design | CA | high capacity internal design |
| Carburization | g5 | inner and outer rings |
| Surface Treatment | S4WC | diamond-like protective coating applied to roller contact surfaces |
| Cage Type | M | two-piece machined brass cage |

| DESIGNATION | ATTRIBUTE | |
|-------------------------------|-----------|---|
| Lubrication Features | E4 | lubrication groove and holes in the outer ring |
| Internal Clearance | CGXXX | custom radial clearance, in microns |
| Surface Finish Specification | U22B | advanced raceway surface finish to promote reduced wear |
| Process Control Specification | U303 | special process control for all NSK wind turbine bearings |

ACCUMULATED EXPERTISE

Optimum engagement with our global technology network and design solutions. Intensive project management. Comprehensive engineering support. For main shaft, gearbox and generator applications alike, NSK deploys our accumulated expertise in collaboration with turbine builders and operators to achieve:

- › advanced design and material technologies for high-capacity, long-life performance
- › innovative solutions to negate unique phenomena such as white etching cracks (WEC) and electrical erosion
- › undeterred equipment performance with condition monitoring
- › control measures and processes - the NSK Wind Standard

With NSK as a development partner our customers embark on a critical path to realizing a high level of performance, predictable reliability and total cost-efficiency in renewable energy generation.



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